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Experimental qualification of the strength enhancement of coated concrete parts

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Abstract
In former own publications e.g. [2] and [3] it was shown, that high precision concrete can be used for machine base frames as a replacement for natural stone. In contrast to base frames, moving parts need to have a high specific stiffness thus requiring a lightweight design. To guarantee reliability comparable to steel or aluminum lightweight parts, the endurance strength of the concrete parts has to be improved significantly. Reinforcement by implementation of steel or carbon fibers is not applicable since it comes with thermal inhomogeneity. As an alternative, reinforcement can also be derived by functional coating. The application of a tailor made sol-gel-coating with enhanced tensile strength like organo-functional silane is a promising approach. The necessary experimental investigation of fundamental effect mechanisms and the coherences to the endurance strength shown at [1] are addressed. The experimental setups and derived results for the determination of the mechanical properties enhanced by the coating are in focus of this contribution. The latest measurments attest the tendencies of a strength enhancement in general. To get more reliable results, the specimen quality and test maschine reproducibility needs to be further improved.

precision concrete, endurance strength enhancement, lightweight construction, organo-functional surface coating

1. Silane surface coating [1]

In order to achieve a predictable and highly reproducible thermal behavior of concrete parts for machine bases and moving parts, special concrete compositions with identical thermal expansion coefficients are applied. This allows massive as well as delicate structures at significantly reduced costs.

The main challenge for the development of concrete light weight parts is the improvement of the endurance strength. Concrete shows high compressional strength but is very sensitive to tensile stress. The tensile load at complex geometry cannot be fully eliminated. Therefore, notch effects and stress concentrations need to be avoided. Reinforcement by implementation of steel or carbon fibers is not applicable since it comes with thermal inhomogeneity.

As an alternative, reinforcement can also be achieved by functional coating. Compressive preload can be implemented to the part surface by applying a tailor made sol-gel-coating with enhanced tensile strength like organo-functional silane. Furthermore, the tensile strength in the sol-gel infiltrated zone is improved and surface micro damages are closed.

2. Mathematical description [1]

A promising approach for the verification of the coating influence is the determination of the stiffness improvement. The stiffness of a coated prismatic geometry is analytically described by a variation of the Young's modulus over the cross section. Assuming a steadily changing stiffness, an hypothetical distribution of the Young's modulus is shown in figure 1. The stiffness change is expressed in form of a harmonic approximation with a sinusoidal approach. The Young's modulus at the rim of the base part and at the outside of the coating is not directly measurable.

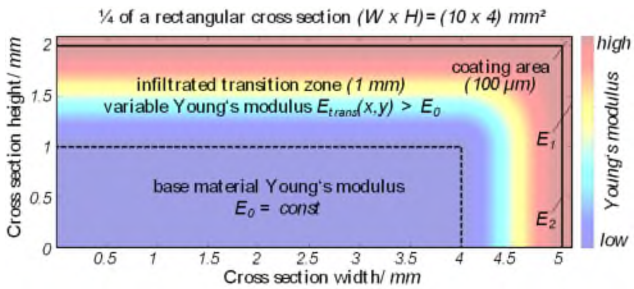

Figure 1. Young's modulus distribution in a rectangular cross section

The dimensions of the coating influenced areas are the infiltrated depth of 1 mm and the 100 µm wall thickness of the coating. The unaffected Young's modulus E_0 of the base part is present within the area limited by the dashed line. The Young's modulus at the outside of the coating E_1 is depending on the pure coating material including existing surface effects. In the infiltrated transition zone the Young's modulus changes from E_0 to E_2 at the rim of the base part (solid line). E_2 is characterized by a maximum sol-gel-infiltration. The relation between E_1 and E_2 is priorly unknown and needs to be determined by experimental verification.

3. Experimental investigations

The mechanical tests are executed with standardized specimen of *DIN 50125 Form E 4x10x35* (figure 2). A central section with a sampling length L of 35 mm is analyzed for both displacement measurements. For the determination of W and H the mean value of four measures along the beams are taken. A tensile load test and a 3-point flexure test are used to obtain tensile and flexural stiffness. The Young's modulus E_0 of the uncoated material is determind by tensile test.

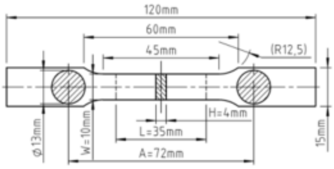

Figure 2. dimensions of the specimen

E_1 and E_2 of the coated specimen are derivated from the tensile stiffness $C_{tensile}$ and the flexural stiffness $C_{flexure}$ measurements in combination by use of the analytic methodology presented in [1]. Here, a finite number of E_1-E_2-combinations with stiffness values $C_{tensile}$ and $C_{flexure}$ concruent to the tests are calculated to find the combination that matches for both tests.

3.1. Tensile test arrangement

A standard test machine is used. To avoid influences of the clamping and machine misalignments, special clamping chucks are designed. To minimize parasitic lateral forces and fatigue the chucks shown in figure 3 (left) allow the auto alignment of the clamp to the specimen axis. For that the center points of the spherical chucks coincide with the specimen's axis.

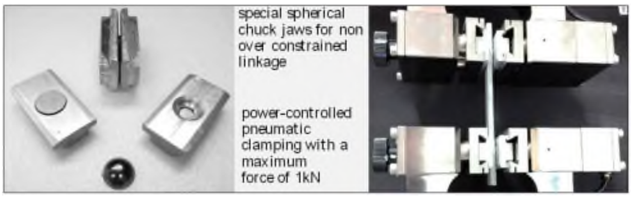

Figure 3. Spherical chucks (left) and tensile test arrangement (right)

3.2. Bending test arrangement

Concrete parts show a characteristically high sensitivity to lateral loads and shear stresses. To realize a 3-point bending test at the none perfect specimen of rectangular cross section, a linear contact is chosen, realised with three cylindrical pins made of steel. Also this setup is designed for self alignment to avoid over constraints.

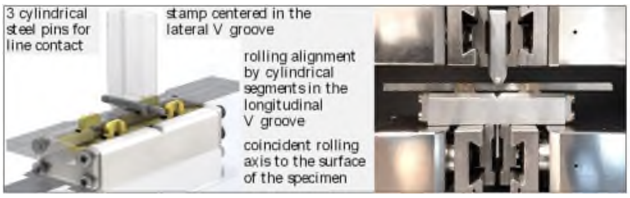

Figure 4. Bending test arrangement

3.3. Measurement of the specimen displacement

For the investigation of new sol-gel compositions a high number of specimens are needed, to derive statisticaly confident results. The displacement measurement is done by the internal length measuring system of the testing machine. The specimen displacement is calculated in consideration of the in-line arrangement of the machine stiffness and the specimen stiffness.

To validate the elongation of L (figure 2) a transmission factor for the implication of the cross-section is used. In figure 5 an exemplary simulation of the specimen deformation caused by the clamping is shown. The second picture from the left shows the clamping situation before applying a longitudinal load. It can be seen, that a deformation of the specimen generates forces in the longditudinal direction, causing a measurement errors.

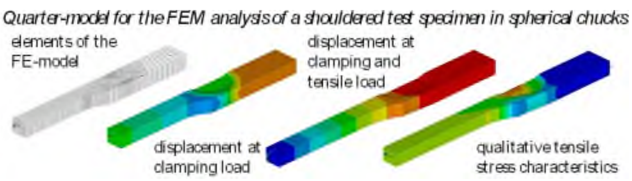

Figure 5. FEM results for tensile load with respect to the clamping force

4. Experimental results

4.1. Stiffnesses of the test setups

To investigate the test arrangements stiffness, specimen of significant higher stiffness were used. The buckle at the tensile load curve shown in figure 6 (left) is induced by a setting effect in the clamp. This effect is highly reproducible and can be corrected in the analysis procedure. The progressive behavior at lower forces in the bending test diagram figure 6 (right) is most likely caused by the Hertz contact at the cylindrical pins.

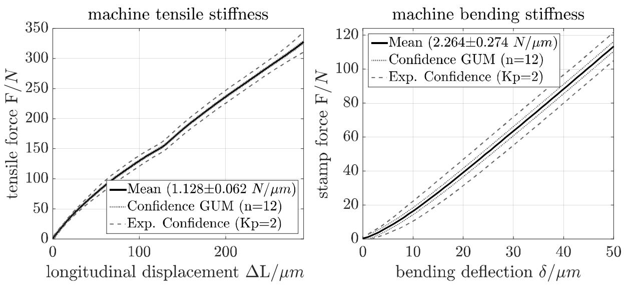

Figure 6. Machines over all stiffness's (tensile-left and bending-right)

4.2. measurements of concrete specimen

Out of a theoretical calculation, the overall systematical uncertainty of the test setup amounts to a maximum ±15%. In contrast to that the stiffness measurement shows a much more widespread distribution, thus not allowing a reliable determination of the Young's modulus trend. This is to blame to the inperfect quality of the specimen. This leeds to the need of an optimization of the manufacturing process for the specimen.

The latest results until the closing date for this contribution allow only an assumption of general tendencies for the stiffness improvement of the coated specimen. The tensile stiffness was improved up to 30% and the bending stiffness up to 58%.

The determination of the coating dimensions (infiltration depth and coating thickness) will be the main objective for commimg investigations.

5. Conclusion

A consistent approach for the calculation of the endurance strength enhancement has been shown [1]. Current results are not jet reliable. Improvements in the measurement of the testing machine stiffness and in the manufacturing of the concret specimen are the next steps. If the distributions of the experimental determined properties are than in the magnitude of the test arrangement uncertainty, the coating parameters for the FE-model can be verified and a statistical reliable prediction of the endurance strength enhancement of concrete parts in lightweight design can be ensured.

Acknowledgements

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References

[1] C. Hahm, R. Theska: D. Raab, A. Fehringer, A. Kästner, *Strength enhancement of precision concrete parts by sol-gel surface coating*, euspen's 17th International Conference & Exhibition, Hannover, May 2017

[2] C. Hahm, R. Theska, *Concrete parts with replicated air bearing path ways*, 2nd Gas Bearing Workshop, Düsseldorf, March 2017

[3] A. Flohr, A. Dimmig-Osburg, C. Hahm, R. Theska, *Sonderbetone für den Präzisionsmaschinenbau*, Concrete Plant International, 2014